The assessment of a site for vhf

by J. STEBBINGS, G4BTV*

MUCH HAS BEEN WRITTEN about the propagation of vhf signals, taking into account the topography, the radio refractive index, heights of antennas, and other factors. The usual treatment is confined to a specific path between two given points on the earth's surface; and simple methods of plotting the path profile may be found in [1], [2].

The author decided to take the matter a bit further and to plot the obstructions to radio waves around the full circle to give a "radio panorama" from the home station located on the south coast of England near the Isle of Wight. The work proved to be quite simple, involving the study of suitable maps, the repetition of a simple calculation; and the plotting of heights on a graph. It is, however, rather time-consuming, but after a system had been established the work could be taken up or broken off as convenient.

There were many surprises as the work progressed, and the final result was very rewarding and gave quite a different view of the site from the impressions gained from local travels over many years.

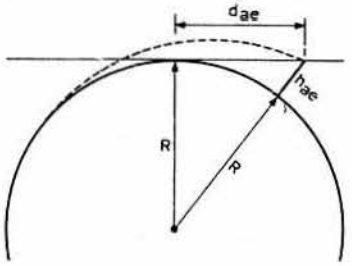

Fig 1. Height of antenna (h_{ae}) gives a line-of-sight distance to the horizon (d). Earth radius = R

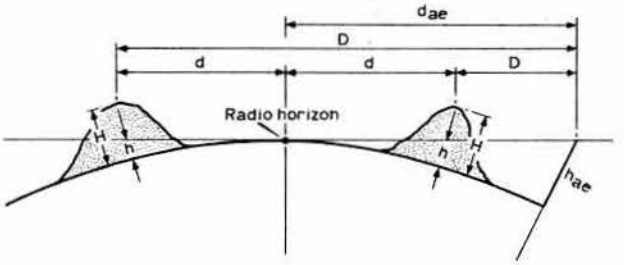

Fig 2. The effect of obstructions of height H at distance D from the station. D may be less than or greater than the radio horizon distance d_{ae}. The distance of the obstruction from the horizon circle is d

Line-of-sight vhf paths

Fig 1 shows the distance to the horizon (d_{ae}) from an antenna at a height (h_{ae}) above sea level. The earth's radius is R, and it is shown in the appendix that $d_{ae}^2 = 2R \times h_{ae}$.

Due to atmospheric refraction, radio waves and, to a lesser extent, light waves are not propagated in straight lines. The path is curved towards the earth, as shown by the dotted line, and the radio horizon is at a greater distance than d_{ae} in the figure. The problem can be overcome by introducing a refractive index factor, K, by which the earth's radius is multiplied so as to permit radio paths to be plotted as straight lines. K may vary from place to place and from time to time, but the usually accepted average value of 1·33 has been used. We therefore have: $d^2_{ae} = 2h_{ae}$ where d_{ae} is in statute miles and h_{ae} is in feet. The derivation of this equation and the equivalent metric form are given in the appendix.

In Fig 2, d_{ae} and h_{ae} are again shown, with the addition of a hill which has a height H above sea level. The obstruction may be either between the antenna and the horizon or beyond the horizon, at a distance, d, measured from the horizon circle. In both cases the hill projects above the radio horizon by an amount (H—h) where h is the "dip" below the horizon at a distance d. Using the above equation we have $h = \frac{d^2}{2}$ (feet, statute miles). D is the distance of the obstruction from the antenna.

$D = d_{ae} - d$ up to the horizon

and $D = d_{ae} + d$ beyond the horizon

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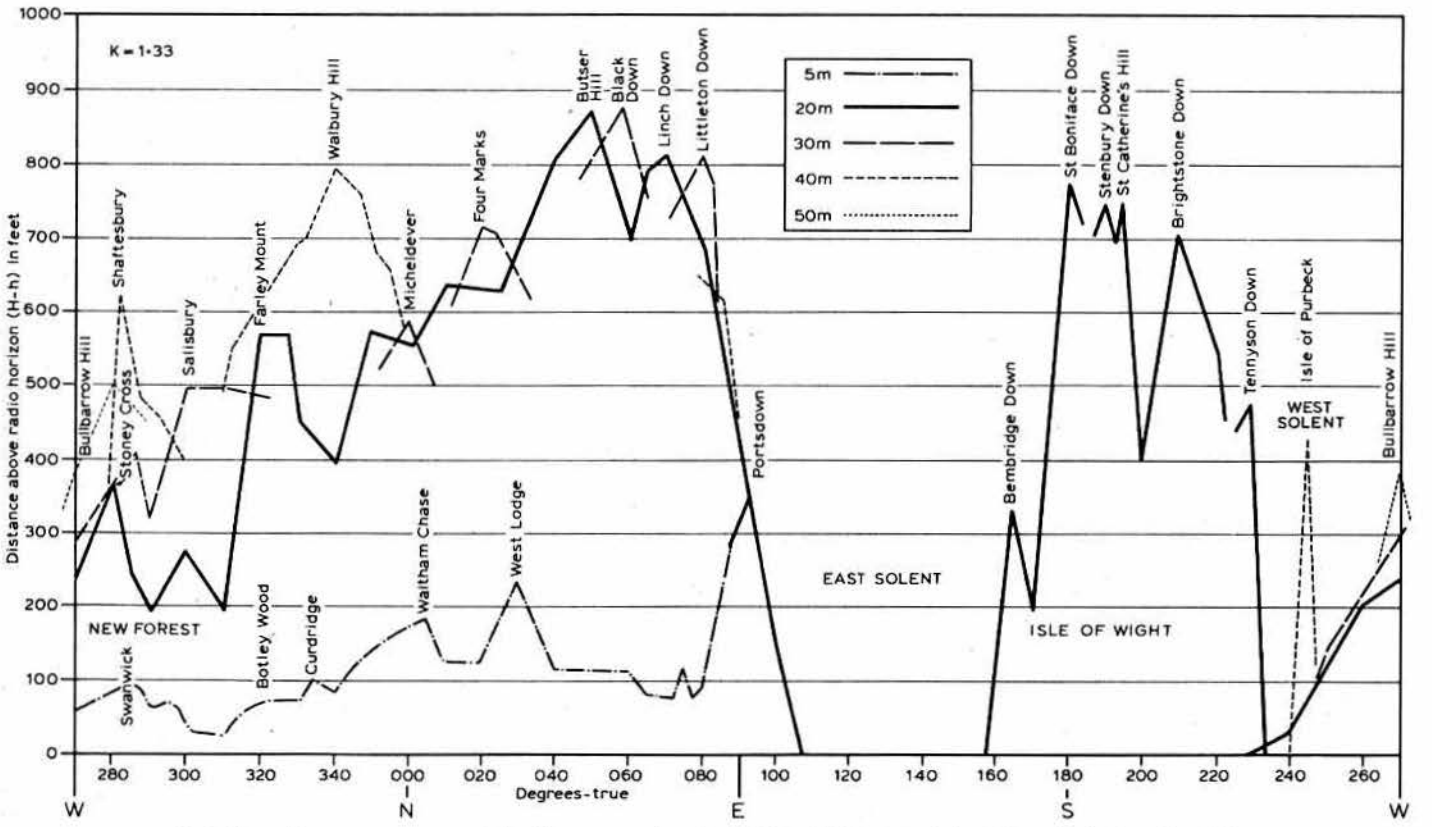

Fig 3. The radio wave panorama, with 360° coverage, showing heights of high ground above the radio horizon. K = 1·33

The "radio panorama"

The object is to tabulate all significant obstructions with their bearings, distances, and heights above the horizon (H – h). Then to plot panoramic profiles for convenient distances from west, through north and east to south, and back full circle to west again.

At first sight the job may seem to be impossibly complicated by the huge number of possible tabulations and the great distances involved. Fortunately, in the author's case, there were limitations. First, small obstructions blanketed by higher ones can be disregarded when the calculation brings this to light. With experience, however, many features may be rejected simply on inspection of the map. A second limitation is on the maximum distance from the site which needs to be considered. For example, when d = 100 miles, h is 5,000ft. So that, except in mountainous country, there is a limiting circle beyond which obstructions will not project above the horizon. In the author's case the limit proved to be 50 miles from the station (D).

The result of the author's endeavours is shown in Fig 3, where the projections above the horizon (H – h) are plotted against true bearings for distances of 5, 20, 30, 40 and 50 miles. Beyond 20 miles the work was done in 10-mile strips. On a given bearing the most significant feature within the strip was found, and its projection above the horizon calculated from the actual distance. This height was then plotted on the distance profile representing the outer edge of the strip. It should be appreciated that the lines joining points on the graphs are not actual ground profiles as in a normal ground section, because adjacent points may not be in the same plane. The lines may be considered as "solid" ground profiles 10 miles thick.

The method

Before describing the system, a few comments will be made on the maps necessary for such an investigation. The "One-inch" (1:63,360) and the metric 1:50,000 series of Ordnance Survey maps allow levels to be estimated within 25ft (7·6m) but the many spot levels given allow a much better resolution. One soon runs out of such large-scale maps and, even if the expense of new maps were justified, the job would get physically too large. They are excellent for nearby terrain, however, and are recommended. Further afield use must be made of the "Quarter-inch" (1:250,000) series on which, unfortunately, the contours are at 200ft (61m) intervals. Nevertheless it soon became evident that by the use of spot levels and a little interpolation, adequate resolution could be obtained. The author used some old "Quarter-inch" maps—hence the use of feet and miles. If a geographical relief map of adequate scale could be obtained, the work would be made easier with the omission of roads, development and other unwanted features.

Fig 4 shows the antenna site with distance circles, the horizon circle, and some of the bearings which were drawn at 10° intervals. The easiest method is to work outwards from the centre. After drawing the bearings the horizon circle, distinguished by colour or form, is added. Remember that the national grid verticals are not true north. To find true north join two identical longitude marks on the top and bottom of the map. This should be done through, or near to, the antenna site. Then add only the two circles defining the strip to be considered. The first strip, of course, will be defined by only one circle and the centre.

For ease of illustration Fig 4 shows the work progressing in the 30–40-mile strip between bearings 280° and 290°. The following remarks, however, are of general application both within and without the horizon circle.

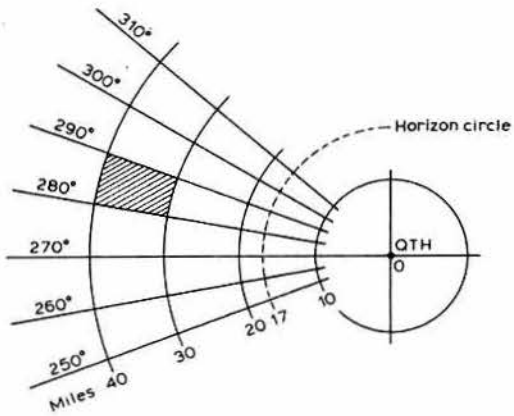

Fig 4. Circles at various distances drawn on the map (including the horizon circle). In this case each area investigated for significant features is bounded by circles 10 miles apart and by radial lines at 10° intervals

Consider an area, such as the one shaded, within the strip and bounded by two adjacent bearing lines. Working outwards look for significant features and tabulate heights and distances thus:

STRIP 40 miles ($d = 30 - d_{ac}$ to $d = 40 - d_{ac}$)					
Bearing	**d**	**H**	**h**	**$(H - h) = H - \frac{d^2}{2}$)**	**Remarks**

If bearings within the 10° sector are required, interpolation may be done by inspection. Continue around the strip and plot the profile before proceeding outwards to the next strip. The plot obtained will help to eliminate many features blanketed by higher and nearer ones.

A column has been shown for h, but it is not essential to record these values if a calculator is used. It is only necessary to compute $h - \frac{d^2}{2}$. The whole study required only 210 lines of the table.

Comments

First, there is no general significance in the strip widths and distances used in this study. They arose simply as convenient values as the work progressed. The omission of a 10-mile circle and the inclusion of one at five miles seemed to suit the local terrain. Other sites with entirely different topography will, no doubt, require other values, determined after some preliminary work. The horizon distance may also affect the choice of strips. As will be seen from Fig 4, it was 17 miles in the author's case.

No account has been taken of trees and tall buildings. Trees are probably only significant when close to the station, where their presence will be known; but tall buildings would be effective at greater distances. They are, however, usually isolated and unlikely to be in the form of a continuous block, particularly on high ground.

The 20-mile line in Fig 3 has been emphasized as a heavy line. This distance seems to dominate the picture and includes all of the Isle of Wight. Topography within the 20-mile circle is very varied, and it was not considered worthwhile to include other circles than that at five miles. The East Solent gap was expected, but is of no value for communication within the UK; oddly, though, little French activity has been heard through it. What was not expected was the narrowness of the West Solent gap with, perhaps, the greatest surprise of all the Isle of Purbeck making its presence felt at 40 miles.

The 20-mile profile constitutes a formidable barrier, but excellent communication should be possible with those areas at greater distances which project above it; provided, of course, that anyone has a station up there or an antenna sufficiently high to reach up! Finally, it has been brought home to the author that he lives in a vast deep radio hole in spite of the magnificent views which may be enjoyed by standing on the roof beside the quad.

It should be noted that K = 1·33 is a mean value about which it fluctuates. It will be less than 1·33 for about 50 per cent of the time and greater for the other 50 per cent.

The method could be extended by using a computer, with adequate graphics, which would allow the value of K to be varied. If additional information from blanketed areas were recorded and profiles displayed on the crt, the value of K could be altered at will. The result would be movement of the profiles relatively to one another exposing regions previously obscured, and vice versa. Perhaps someone with a computer will have a go.

Varying the value of K

The author has extended the study the hard way by plotting two more panoramas for K = 1·0 and K = 2·0. See Figs 5 and 6.

If we keep the value of K in the "dip" formula $h = \frac{d^2}{2}$, it becomes $h = \frac{d^2}{1{\cdot}5K}$ (feet, and statute miles).

We thus have for K = 1·0, $h = \frac{d^2}{1{\cdot}5}$, and for K = 2·0, $h = \frac{d^2}{3{\cdot}0}$, using feet and statute miles. The metric version is $h = \frac{d^2}{12{\cdot}75K}$ (m, km).

The use of K effectively varies the value of the radius of the earth so that the wave path from the antenna may be drawn as a straight line instead of the curve actually caused by refraction.

Before looking closely at Figs 5 and 6 some basic principles may be established by looking at propagation in two dimensions. In Fig 7 a hill is shown between the antenna and the horizon. Its projection above the horizon is reduced as the value of K increases. In Fig 8 the opposite effect is seen when a hill is beyond the radio horizon. The projection is increased when K is increased. The letter S has been used for distance from antenna to horizon (d_{ac}) in order to avoid multiple subscripts.

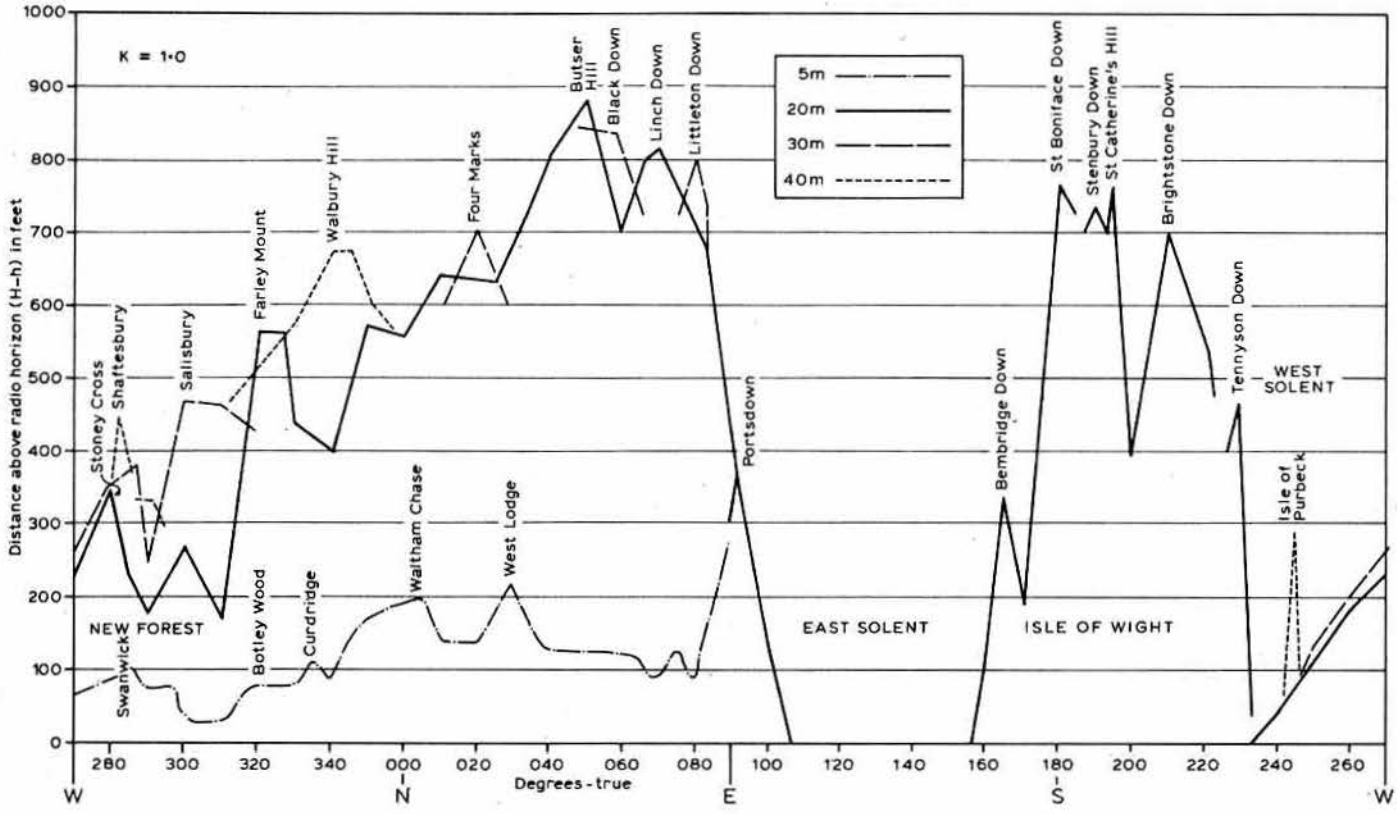

Fig. 5 The panorama of Fig 3 re-drawn with a low radio refractive index (K = 1·0) representing poor tropospheric propagation

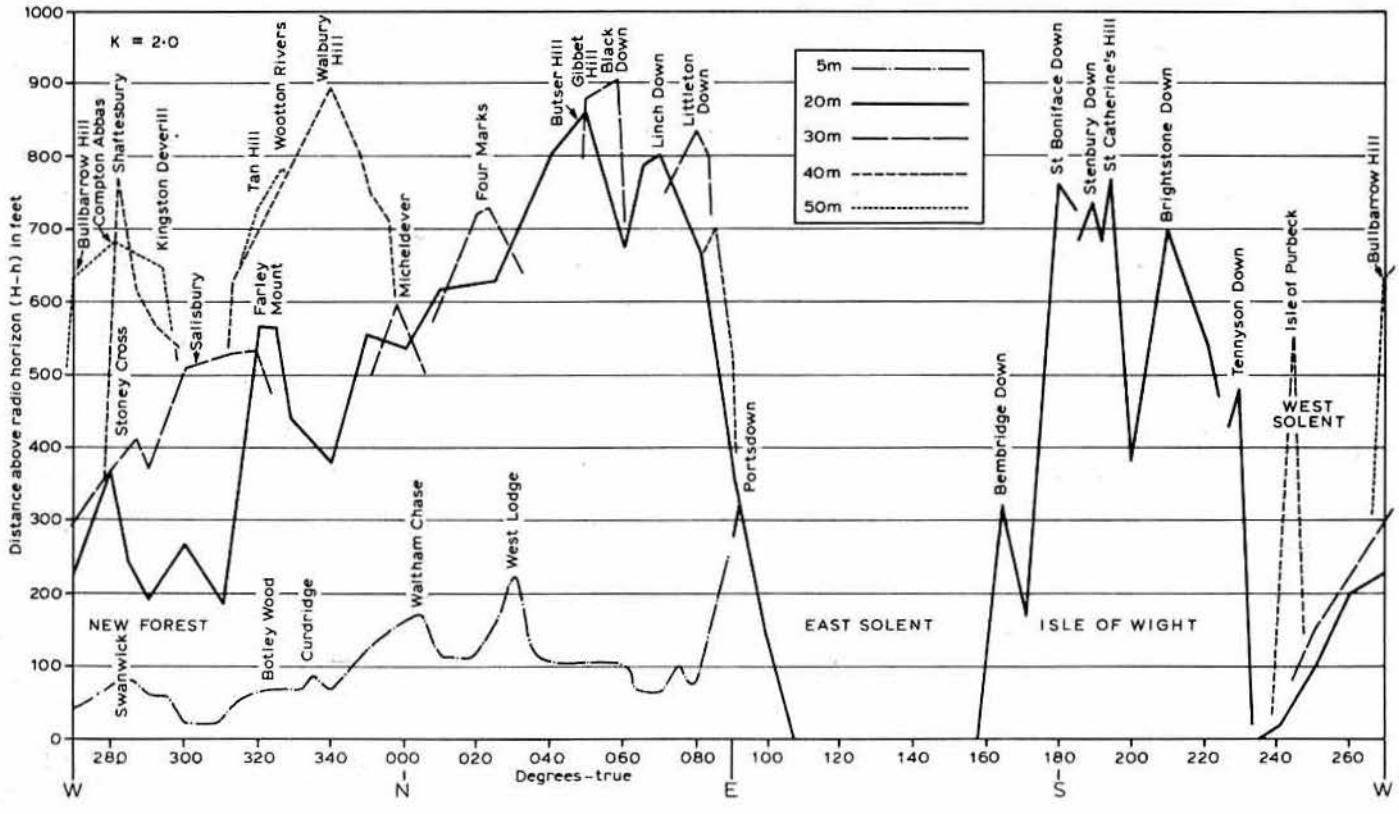

Fig 6. The panorama of Fig 3 re-drawn with a high radio refractive index (K = 2·0) representing good tropospheric propagation

A third interesting phenomenon is illustrated in Fig 8. The horizon distance increases with K from S_a to S_b, and the value of d is therefore reduced. This results in the projection above the horizon increasing rapidly with distance. In Fig 8(a) the distant hill, height H_2, is obscured by the nearer hill of height H_1. When K increases as in Fig 8(b) the distant hill is now "visible" above the nearer one, increasing the possibility of communication with sites on the higher ground of H_2.

It can also be seen from Figs 7 and 8 that the effect of an obstruction situated near the horizon circle changes very little with K. When K = 1·0, d_{ac} (or S_a) = 14·75Sm and when K = 2·0, d_{ac} = 20·85Sm.

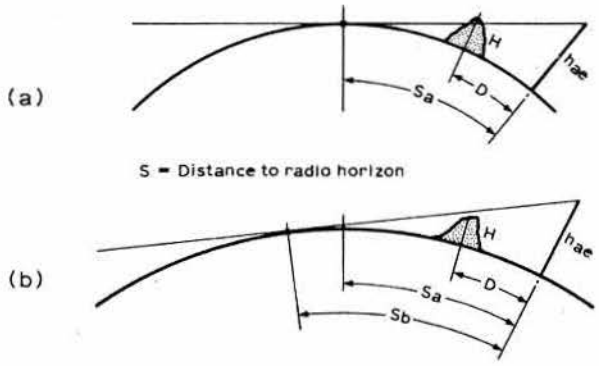

Fig 7. Obstruction between antenna and radio horizon. (a) Low K value. Hill of height H at distance D projects above the horizon line. (b) High K value and greater radius, hill projects less or may even be below the horizon

The effect of K on the panorama

When comparing Figs 5 and 6 it is seen that the five-mile line is depressed as expected, although the difference is small due to the small distance from the antenna. The 20-mile line shows even less change.

Looking at more distant profiles there is nothing "visible" at 50 miles in Fig 5, but in Fig 6 Bulbarrow Hill, Compton Abbas and Tan Hill (265°—330°) appear through gaps in the nearer profiles. The heights of Shaftesbury (285°), Walbury Hill (340°), and the Isle of Purbeck (245°) all at 40 miles, show a marked increase in height above the radio horizon.

Due to the fact that profiles represent 10-mile-wide strips, there can be relative movement of two points on the same profile at different distances within the same 10-mile strip. The effect is small and probably not significant, but it can be seen at Walbury Hill (340°), Four Marks (020°), and on the 20-mile profile below Four Marks. There is a change of shape or slope due to individual plots (not shown) moving relative to one another.

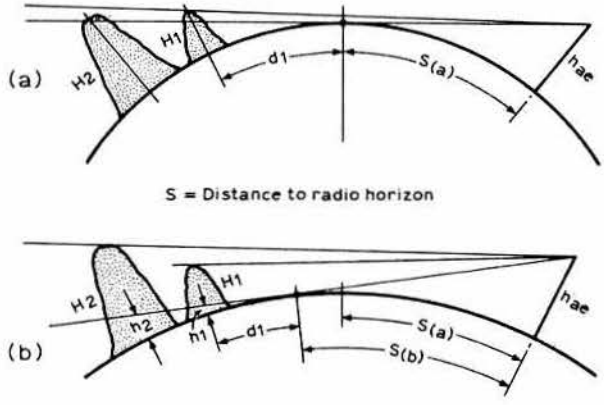

Fig 8. Obstruction beyond radio horizon. (a) Low K value. Hill H1 obscures hill H2. (b) High K value and greater radius. H2 now "visible" above H1

Conclusions

The extension of the original work has emphasized the following phenomena due to an *increase in the value of K*:

(a) The effective height of an obstruction located between the antenna and the horizon is reduced.

(b) The effective height of an obstruction beyond the horizon is increased.

(c) Changes in the value of K have little effect on obstructions near to the horizon circle.

(d) Obstructions at great distances beyond the horizon may become "visible" above nearer ones also beyond the horizon.

The use of a single value of K for the whole of the propagation path is, of course, a considerable simplification of the problem. Not only will K vary along the path but it will also vary with height. Therefore the wave path, which is curved in practice, will pass through different K values in two dimensions (or even three dimensions?).

Nevertheless, the panoramas which have been plotted show in general terms the likely propagation from the site both at low values of K (poor conditions) and at high values (good tropospheric propagation).

Figs 5 and 6 seem to explain why the first distant stations to be heard are from the West Country (W Solent gap) and from Somerset and South Wales (Salisbury gap). London stations are seldom heard (045°).

References

[1] "Microwave path checking", B. Chambers, G8AGN. *Rad Com* February 1978, p122. RSGB.

[2] "Microwaves", Charles Suckling, G3WDG. *Rad Com* March 1981, p241. RSGB.

[3] "Propagation." Ch 2. *VHF/UHF Manual* 3rd edn. 1976. RSGB.

Appendix

Consider the path of a radio wave from an antenna height h_{ae} above sea level as in Fig 1. R is the radius of the earth, d_{ae} is the distance to the horizon. By Pythagoras:

$$(h_{ae} + R)^2 = d^2_{ae} + R^2$$

$$d^2_{ae} = h^2_{ae} + 2Rh_{ae}$$

As h_{ae} is very small compared with R, h^2_{ae} may be neglected. Therefore

$$d^2_{ae} = 2Rh_{ae} \quad \ldots\ldots(1)$$

Introducing K to allow for refraction this equation becomes:

$$d^2_{ae} = 2R'h_{ae} \quad \ldots\ldots(2)$$

where $R' = K \times R$

An average value for K is 1·33.

The earth's circumference is divided into 21,600 nautical miles being 360×60 minutes of arc. R is therefore $\frac{21,600}{2\pi} = 3,438$ nautical miles. $R' = 1{\cdot}33 \times 3,438 = 4,572$ nautical miles or 5,265 statute miles, and equation (2) becomes:

$$d^2_{ae} = \frac{2 \times 5265}{5280} h_{ae}$$

$$\text{or } d^2_{ae} = 2h_{ae} \quad \ldots\ldots(3)$$

where d_{ae} is in statute miles and h_{ae} is in feet.

If d_{ae} is in kilometres and h_{ae} is in metres then

$$d^2_{ae} = 17h_{ae} \quad \ldots\ldots(4)$$

BOOK REVIEW

Amateur Radio—Theory and Practice by Robert L. Shrader, W6BNB. Published by McGraw-Hill Book Company. 340 + xii double-column pages (235 by 185mm). First edition 1982. Soft covers £11.50.

This new book has one aim: to explain, in simple terms, the basic radio theory needed to pass any and all of the amateur radio licence examinations of the Federal Communications Commission (FCC). These include novice, technician, general, advanced and extra-class grades in the classic American incentive licensing system. The text includes a check-up quiz every few pages and paragraphs are prefixed with the letters N, G, A etc to indicate that the information is required for specific grades of licence. For American readers it would seem to have much to offer and, apart from one or two chapters, appears to be a sound and reasonably up-to-date primer. It is considerably longer and more detailed than any comparable British publication, including the Society's *Radio Amateurs Examination Manual*. It treats both solidstate and thermionic devices, has a chapter on "advanced amateur systems", another on "digital fundamentals", and there are sections on the j-operator, decibels, Smith charts and the like.

All this is both good and bad news for those intent on taking the British RAE. Many candidates would be confused and put off by the problem of relating American examination requirements with the City & Guilds syllabus and the British licence conditions. It is probably more suitable for someone who has just passed the RAE but wishes to extend and improve his knowledge of fundamental radio communications theory. A word of warning. The *Antennas* chapter, including transmission lines, baluns etc, has a curiously old-fashioned look and contains both errors and descriptions that are likely to mislead the reader. For example, the short note on Yagi antennas is not only based on the original λ/4 spacing but also includes the odd notion that a two-element Yagi is bi-directional with the single parasitic element acting as *both* reflector and director. W6BNB must have been singularly unfortunate in his front-to-back ratio! Emission modes are designated in the pre-WARC manner (A3J etc), a problem that is likely to persist for almost as long as Mc/s.

In brief, a better-than-average book on radio theory for amateurs but not really suitable as an examination manual in the UK.

Chapters: *Amateur radio. DC circuits with resistance. Alternating current, inductors, capacitors and transformers. Reactive circuits. Resonance and filters. Transistors and vacuum tubes. Power supplies. AF and rf amplifiers. Oscillators. CW transmitters. CW receivers. Radio waves. Antennas. Amplitude modulation systems. Single-sideband systems. Frequency modulation systems. Measuring devices. Digital fundamentals. Advanced amateur systems. Radio-frequency interference. Learning code and operating. Amateur rules and regulations. Seven appendices. Index.*

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